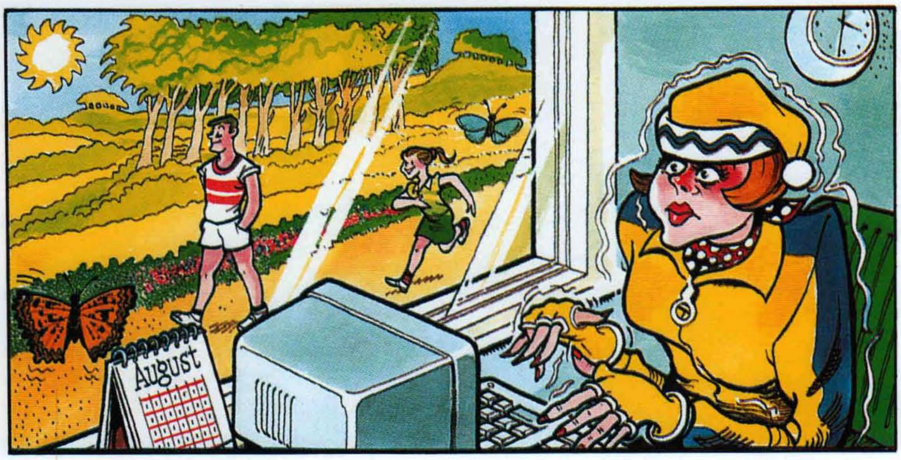
Guide 71

Selecting air conditioning systems

A guide for building clients and their advisers

The purpose of this document is to:

- highlight the importance of selecting appropriate air conditioning systems for new developments
- show the effects on costs and on the environment
- explain the jargon.



Introduction

Energy consumed to heat, light and service buildings accounts for almost half of the nation's energy bill, and there is considerable scope to reduce it.

In air conditioned offices 30% to 40% of the energy bill is typically attributable to air conditioning alone. This represents not only a very significant cost to the individual user, but also results nationally in the emission of millions of tonnes of carbon dioxide, which is the major contributor to the greenhouse effect. CFCs, which have traditionally been used as refrigerants, also contribute to the environmental cost of air conditioning since when released they cause the depletion of the ozone layer and also contribute to the greenhouse effect.

In a large number of buildings full air conditioning is not really necessary and large savings can be made by using mechanical or natural ventilation instead. The use of mechanical ventilation or partial air conditioning (mixed-mode operation) should also be considered before deciding to air condition the entire premises. These decisions should be made early in the design process.

Where air conditioning is necessary, BRECSU estimates that up to 30% of the typical energy cost can be saved by ensuring the following:

- appropriate selection of the air conditioning system
- energy-conscious design of the installation
- good control of the system
- effective commissioning and maintenance of the system.

This brief Guide addresses the first of these, and is aimed at building clients and users who may then discuss the options with their design teams in greater depth. It is an attempt to ensure that the implications of different options for air conditioning are fully considered during the early stages of the design process by providing a basis for discussion with design teams. It must be emphasised, however, that even the most appropriately selected air conditioning system can be expensive to operate if it is not well designed, controlled and maintained.

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Experience has shown that air conditioning system selection is often made only after decisions have been made relating to plantroom size, duct space, architectural features, etc. This often excludes energy efficient options which would have otherwise been acceptable.

Important issues for the potential user to consider are highlighted by the following questions. The answers will indicate the type of system most appropriate to the application, and whether air conditioning is needed at all. These questions need to be addressed as early as possible in the design of the building.

Air Conditioning

The phrase "air conditioning" is often used to represent a wide variety of levels of service, from mechanical ventilation to sophisticated systems giving close control of temperature and humidity.

The degree of sophistication required affects the type of plant selected and, to some extent, both capital and operating costs. Not all types of plant offer all the features that may be required. In this Guide the term "air conditioning" will be reserved for systems providing cooling of air as a minimum.

Key Questions

What are your requirements?

Figure 1 presents a decision tree which indicates the appropriate types of plant for different sets of requirements. The questions in Figure 1 are discussed below. For large and complex buildings, different requirements may indicate that separate systems are appropriate for discrete parts of the building. This is not unusual. The most common types of system are described later in this Guide and Tables 1 and 2 summarise their important features.

In some circumstances, for example in city centres and other noisy and polluted areas, it is undesirable to open the windows of a building. This does not necessarily mean that air conditioning is required. Mechanical ventilation techniques may be acceptable. Where such problems do not exist the psychological advantages of opening windows and the part they can play in natural ventilation and cooling should be considered.

i Does your application have to account for consistently high heat loads?

Many air conditioning applications are simply required to provide comfortable conditions for people in a room space. In specific cases, however, particularly high cooling loads are imposed on the plant by electronic equipment within the space (eg mainframe computers), by a high density of people, or some other particular heat source.

For these cases some form of chilling is likely to be required. Ventilation using ambient air alone is unlikely to be able to cope with such loads. It may be worth examining whether the loads themselves can be reduced.

ii Does your application require close control of humidity?

Close control of humidity is required in a few applications to protect, for example, electronic equipment, magnetic tape or disks, books and other sensitive materials. Human beings are more tolerant, and often in the UK humidity control is not necessary at all for comfort.

Humidity is measured in terms of relative humidity. This concept allows for the fact that warm air will feel drier than cooler air if the same amount of water is present. Most people are perfectly comfortable within a range between 40% and 70% relative humidity. UK weather conditions mean that if air conditioning is set to maintain a temperature of 23°C in summer, this humidity comfort band is not exceeded for more than a few hours on one or two days in a typical year, even in the most humid part of the country (South East).

Occasionally over-dry air can cause problems with static electricity and with respiration. Hence, in some circumstances, there is a need to increase relative humidity by mechanical means.

Humidification imposes a significant maintenance burden and hazards from poorly operating humidifiers include humidifier fever, legionnaires' disease and sick building syndrome.

iii Will it be acceptable for your space to reach 28°C on the few hours each year when outdoor temperatures reach this level?

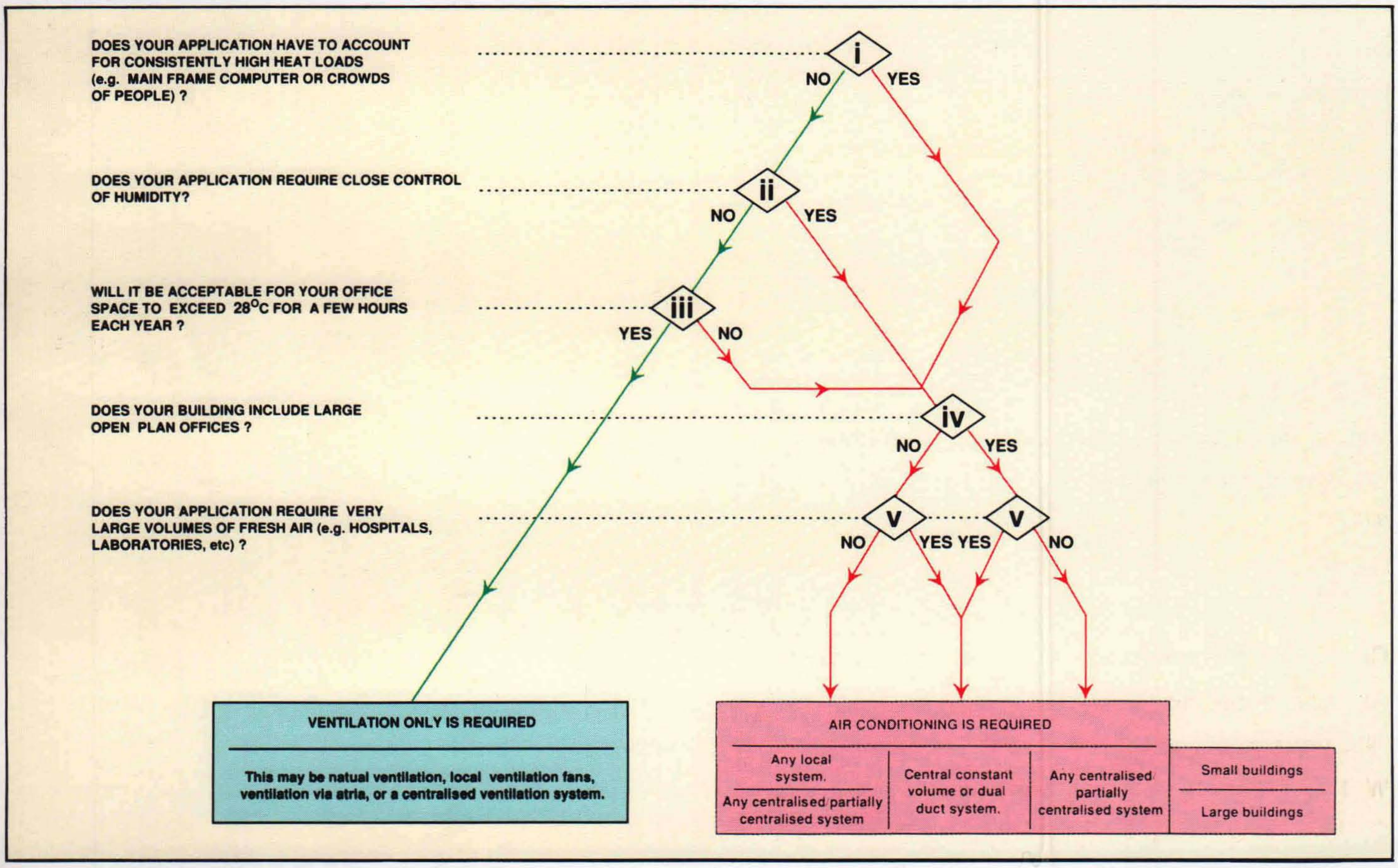

Figure 1 What are your requirements?

The Technical Options

There are three generic types of air conditioning system, with many variations available within each, as shown in Figure 2.

- **Centralised air systems,** in which all the heating and cooling is carried out in a central plant room and conveyed to the rooms by ductwork.
- **Partially centralised air/water systems,** in which centrally cooled or heated air is further heated or cooled at entry to the rooms.
- **Local systems,** in which all operations are performed locally.

The potential for variations and combinations of types of system is limited only by the designer's imagination.

For example, in relatively large spaces (open plan offices, hotel lobbies, etc) with outside walls it is common to separate the system which deals with the outside wall (perimeter), where the need for winter heating is the greatest, from the interior space. Often a central air system may serve the interior, and radiators or skirting heaters may be used at the perimeter. Alternatively two separate central air systems may be used.

Since it is easier to control heating rather than cooling, most centralised and partially centralised systems reheat air which has previously been over-cooled. The waste incurred can be minimised by careful design and control.

The following discussion is intended to describe the principal options for air conditioning.

Centralised air systems

These systems are typically based around a pre-packaged air handling unit (AHU) which consists of a fan, and combinations of heating and cooling coils, filters, humidifiers and control dampers. They may also include packaged heat pumps and an exhaust fan and/or the facility to recycle exhaust air back into the building. The AHU would normally be located within a plant room with chillers and boilers located nearby.

When outside air is cooler than desired in the air conditioned space, fresh air can be introduced and chilling is not required. In the UK, this "free cooling" should be made available to minimise the need for refrigeration.

AHUs can be configured to serve several different types of distribution system.

Constant volume single zone systems are simple, relatively low cost and easy to commission, but cannot provide adequate control for areas (zones) with different and simultaneous heating or cooling needs. Several separate systems may be required to serve different zones, increasing capital costs and plant room space.

Variable air volume (VAV) systems address the problem of zones with different requirements by varying the quantity of air supplied to each zone. The air is supplied at a constant temperature through thermostatically controlled damper units (referred to as VAV boxes). The volume of air and hence the amount of cooling is varied to meet the requirements of each zone. There is normally the facility to reset the 'constant' temperature.

The use of VAV boxes means that some maintenance of the boxes themselves, which are usually located in ceiling voids, must be carried out in the occupied space. However maintenance requirements are low, and this should not be a major obstacle.

Within the VAV concept the designer has several options open to him, including fans to re-circulate room air and bypassing of air which is not required back to the extract fan (rather than simply reducing the flow). Recirculating fans reduce the problem of supplying widely varying volumes of air through a single diffuser without creating draughts, but can introduce noise into the room and add to maintenance requirements.

Bypassing of air by VAV boxes does not affect comfort in the rooms and simplifies system design. However, this approach fails to take advantage of two potential benefits of the VAV system. Firstly the cooled zones will not all require maximum cooling at the same time, and selection of the AHU taking into account the reduced requirements of some areas should reduce capital costs.

Secondly, in most applications maximum cooling is required for very few days each year and a true variable volume system will result in much lower air requirements for most of the time. This will result in significant energy savings from reduced fan power and heating and cooling of air.

VAV systems are primarily for buildings with a year round cooling demand. They can normally be smaller than the equivalent multi-zone system because the design does not need to allow for full cooling simultaneously in all zones.

Dual duct systems can incorporate either constant volume or VAV principles. As the name implies, two ducts are used, one carrying heated and one cool air to the space, where the air is mixed in a thermostatically controlled mixing box, usually mounted in a false ceiling.

These systems give accurate control of space temperature, but capital costs and space requirements are relatively high because two sets of ductwork are required. In their constant volume form, dual duct systems will often mix air which has been heated (using energy) with air that has been cooled (using energy).

Partially centralised air/water systems

The common factor with these systems is that a central AHU, as described above, is used but further conditioning in the room may be locally controlled.

Partially centralised multizone and VAV systems allow free cooling by damper control at the central air handling unit.

Centralised air systems with reheat of both constant volume and VAV types are available where the central air supply is further heated or cooled to room requirements by additional heating or cooling coils (batteries). In constant volume systems this greatly improves controllability and the ductwork can be configured to serve rooms with quite different requirements (referred to as **Constant volume multizone systems**). Heating and cooling coils can be located either within ceiling voids (partially centralised system) or in the plant

CHECKLIST

What is the gross floor area of your building?	**............... m^2**
Hence what is the capital cost of your chosen system? (from table 2)	**£ ....**
What is the energy cost? (from table 2)	**£ .... per year**
What is the environmental cost? (from table 2)	**£ .... tonnes CO_2 per year**
Have you considered free cooling?	**Yes / No**
Are cooling loads as low as possible?	**Yes / No**
Can air or chilled water temperatures be raised?	**Yes / No**
Are you avoiding CFCs?	**Yes / No**
Will your designs be thoroughly optimised for capital and energy?	**Yes / No**
Will your system be well controlled?	**Yes / No**
Do you really need air conditioning throughout?	**Yes / No**
Do you really need air conditioning at all?	**Yes / No**

	Level of control	Filtration	Noise level	Space required: Plant Room	Space required: Office	Space required: Duct	Humidity control	Maintenance: Local or Central	Maintenance: Skill Level	Suitable for mixed mode	Air Distribution
Centralised Air Systems											
Ventilation and heating - no air conditioning	Good	Good	Low	High	Low	High	None	Central	Medium	Yes	Very Good
Constant volume (Single zone)	Very Good	Good	Low	High	None	High	Very Good	Central	High	Yes	Very Good
Variable air volume (VAV)	Good but complex	Good	Low	High	None	High	Good	Both	High	Yes	Very Good
Dual duct	Good	Good	Low	High	None	Very High	Good	Both	High	Yes	Good
Partially Centralised Air/Water Systems											
Centralised air with reheat	Good	Good	Low	High	None	High	Good	Both	High	Yes	Good
Induction units	Poor	Poor	Can be High	Low	None or Moderate	Moderate	Limited	Both	High	Yes	Poor
Fan coil units	Good	Poor	Can be High	Low	None or Moderate	Moderate	Limited	Both	High	Yes	Fair to Good
Unitary heat pump	Good	Poor	Can be High	Low	Moderate	Low	None	Both	High	Yes	Poor
Local Systems											
Heat and local ventilation - no air conditioning	Can be Good	Can be Good	Can be High	None	Low	None or Low	None	Local	Low	Yes	Can be Good
Through wall packages	Local only	Poor	High	None	Moderate	None	None	Local	High	Yes	Poor
Split unit packages	Local only	Poor	High	Low	None to Moderate	None	None	Local	High	Yes	Poor
Individual reversible heat pumps	Local only	Poor	High	Low	Moderate	None	None	Both	High	Yes	Poor
Variable refrigerant flow rate	Good	Poor	Can be High	Low	None or Moderate	None	None	Both	High	Yes	Fair

Ventilation and heating systems are shown for comparison with air conditioning systems

Table 1 Features of air conditioning systems

	COSTS: Capital £/m^2	COSTS: Energy £/m^2/year	COSTS: Maintenance	CO_2 Emission kg/m^2/year
Centralised Air Systems				
Ventilation and heating - no air conditioning	100	1.9	Medium	30
Constant volume (Single zone)	160	3.0	Medium	50
Variable air volume (VAV)	180	2.4†	Medium to High	40†
Dual duct	210	3.4	Medium	55
Partially Centralised Air/Water Systems				
Centralised air with reheat	200	3.1	Medium to High	50
Induction units	160	3.2	High	50
Fan coil units	170	3.2	High	50
Unitary heat pump	130	3.2	Medium to High	55
Local Systems				
Heat and local ventilation - no air conditioning	90	1.1	Low	17
Through wall packages	70*	3.5	Low	75
Split unit packages	85*	3.5	Medium to High	75
Individual reversible heat pumps	110	3.0	Medium to High	55
Variable refrigerant flow rate	130	2.8	Medium to High	50

†system fitted with variable speed fan.
* excludes separate provision of heating.
Figures are indicative only, and detailed calculations are necessary before comparisons are made. The numbers and ranking may be affected by building use and the design of the chosen system.
Capital costs exclude related building work and cost of building management systems.
Ventilation and heating systems are shown in comparison with air conditioning systems.

Table 2 Air conditioning system costs (areas referred to above are the total building area measured inside the external wall, ie the gross floor area)

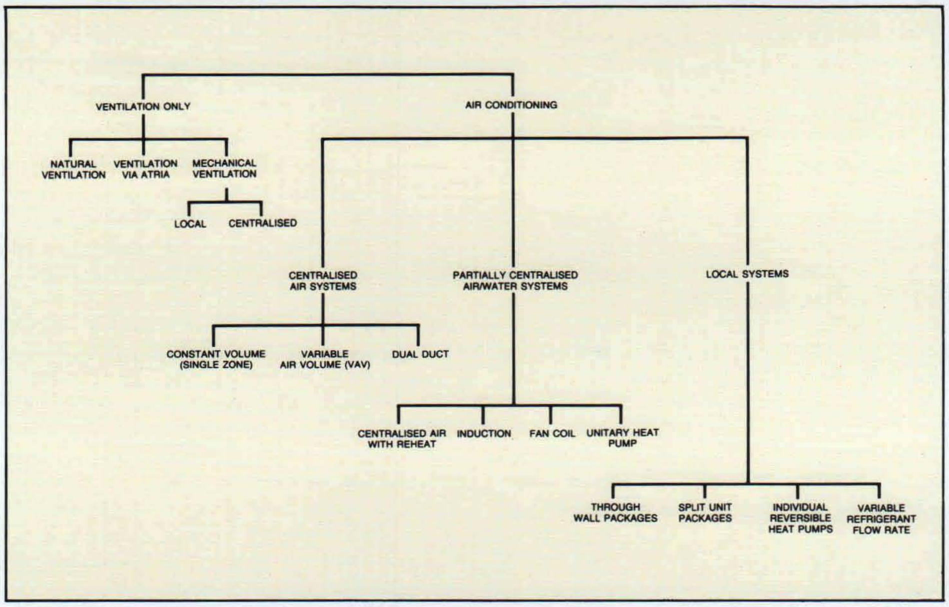

Figure 2 Types of air conditioning system

Even in the warmest parts of the UK, outdoor temperatures exceed 28°C for only 10 hours and 25°C for only 40 hours in a typical year. Even when the outside temperature is 28°C, the temperature inside the building may well be lower.

Discomfort inside buildings in hot weather is compounded by factors other than just temperature and high humidity. Lack of air movement and direct sunlight can also contribute to discomfort. A well designed ventilation system which can include opening windows and external solar screening can overcome this. Thus, in many situations, the need for air conditioning can be eliminated altogether by removing the other causes of discomfort.

iv Does your building include large open plan offices?

Large open plan spaces limit the types of plant which may reasonably be used. This tends to imply the use of centralised systems (or partially centralised) even for relatively small buildings. In situations where the open space may later be partitioned flexibility is important and VAV systems are usually the least costly to modify.

v Does your application require particularly large volumes of fresh air?

A plant room associated with a centralised air conditioning system

In certain specific applications, the space to be air conditioned requires large volumes of fresh air. This is true in hospitals, laboratories, and certain food industry applications, for example.

Using your answers to questions i to v and the decision tree (Figure 1), you can now identify the type of system you require. Where this system fits in the overall range may be identified from Figure 2, and its estimated capital and energy costs from the next section.

How much will the system cost to install and operate?

Table 1 summarises the features of different types of air conditioning and Table 2 gives indicative capital and operating costs. These represent very generalised costs for relatively modern, well controlled, medium to large office premises, and specific installations can vary greatly from the figures shown.

There are techniques that can be used to estimate air conditioning costs early in a project. These are beyond the scope of this document but can be carried out by mechanical and electrical consultants, contractors or cost consultants. Having established relevant capital and operating costs, the next step is to determine whether they are close to the lowest figures.

What are the costs of the alternatives?

By carefully evaluating all relevant alternatives it may be possible to save 20% or more in capital and/or running costs.

As shown above, the choice of system for a particular application is complex, affected by the use of the building and other practical issues, and also by building size. In addition, different organisations will have different views on comfort levels, the importance of energy and the environment, and different criteria for investment in energy efficiency. It is not possible to provide specific guidelines. The different types of system are described opposite.

Variable Air Volume (VAV)

A variable air volume (VAV) system is a centralised air conditioning system which supplies a variable volume of constant temperature (and humidity) air to each area of the building.

Constant Volume

Constant volume air conditioning systems deliver fixed volumes of air to the different areas of a building. The air can be heated, cooled, humidified or dehumidified as appropriate.

Fan Coil

Fan coil air conditioning systems deliver chilled water to fan-assisted cooling radiators in each area of the building. Fresh air is normally supplied from a central system.

Mechanical Cooling

Mechanical cooling is the use of refrigeration to cool the building, either through chilled water or chilled air.

Free Cooling

Free cooling is the use of ambient conditions to generate chilled water or the use of cold fresh air to cool a building. It should always be made available.

Mechanical Ventilation

Mechanical ventilation, as opposed to natural ventilation, makes use of fans to supply and extract fresh air to and from the building.

Fan Power

It should be noted that fan power accounts for a very high percentage of energy consumed for air conditioning and that appropriate ducting design can reduce fan size and energy consumption in central air systems.

Is your system optimised?

Simply selecting the most appropriate system type is not the whole story. The system then needs to be properly designed otherwise many of the benefits will be lost.

The optimisation technique is relatively complicated, but your consultant should be able to advise.

Key points to consider are:

- reducing cooling demand
- optimising air/water temperatures and flow rates
- selecting efficient components
- free cooling.

Air conditioned office

room (fully centralised system). In the latter case this can increase capital costs and space requirements, since separate ducts must run between plant room and each zone.

In VAV systems usually only reheating coils are provided located within the VAV box (**VAV with reheat**). This has the disadvantage that hot water must be piped to the VAV boxes and there is some potential for leaks within the occupied areas. The system does, however, give good control for areas with widely varying loads, and reheat need only be applied to some VAV boxes where heating needs are greatest, for example in perimeter areas.

Induction systems use air from the central AHU (primary air) injected through nozzles to induce circulation of room air over a coil to which heating or cooling is applied. Primary air is generally limited to the minimum amount of fresh air required for ventilation, and the opportunities for free cooling and humidity control are therefore restricted.

Hot and chilled water is supplied to each room by two pipe (one supply, one return), three pipe (hot and chilled supplies, common return) or four pipe systems (hot and chilled supplies and returns). Only four pipe systems give good control and energy efficiency and should always be used.

Centralised control of induction systems is complicated but most units are fitted with manually controlled dampers to control the flow of re-circulated air.

Central plant room and ductwork space requirements are low although the induction units themselves are often mounted below windows occupying floor space. Ceiling mounted units are available but not widely used.

Each induction unit requires maintenance and cleaning which must be carried out in the occupied area. The hissing sound of the primary air issuing through nozzles can also cause a noise nuisance in the occupied area.

Fan coil systems are similar to induction units except that air is moved by a fan, rather than induction. Fresh air can be supplied from an AHU or drawn directly from outside by the fan (not common in UK). In some types of unit this fresh air can be used to provide free cooling as described above.

Units can be perimeter or ceiling mounted, and modern fans are surprisingly quiet. Noise can still be a problem, however, and maintenance of a large number of units can be difficult.

Induction unit and fan coil unit systems normally have a full fresh air supply from the air handling unit. This provides the minimum fresh air requirement and is therefore a much lower volume than an equivalent multizone system. It requires reduced AHU and duct size, although induction systems may have an increased requirement over fan coils due to the need to induce room air.

Where heating and cooling is required at induction or fan coil units, four pipe systems must be used.

Unitary heat pump systems are available which use a constant temperature water (two pipe) loop for the hot and cold sources. Heating (from a boiler) or cooling (often from a cooling tower) is supplied to the water loop in the central plant room area. The heat pump units, which incorporate fan coil units, use this loop to provide or take away heat when cooling or heating is required by the room.

Local systems

The phrase "comfort cooling" is more appropriate to most local systems since summer cooling only is normally provided. Other air conditioning functions such as fresh air supply, humidity control and heating are not necessarily available.

These systems are characterised by the installation of one unit per conditioned zone when only small parts of a building require conditioning or if conditioning is to be introduced one room at a time.

Through-wall packaged units are popular in Mediterranean areas but unusual in the UK. The units are generally a small refrigeration unit with an integral air circulation fan. Air is drawn from the room, cooled and returned. Heat removed from the air is passed to the outside of the wall and rejected to outside air.

The units are simple, low capital cost, easy to use and offer the facility for local user adjustment but poor space temperature control due to sensor location and on/off control action. They require wall mounting, can be noisy and are not generally very efficient. The maintenance requirements of a large number can be difficult and most units do not readily adapt to central control.

Some units offer heating by electric elements which can be expensive in use.

Packaged "split units" are much more popular in the UK. The room mounted part of the unit resembles a fan coil unit, but cooling is provided by refrigerant rather than chilled water. The refrigeration part of the unit can be located away from the occupied area. They offer more sophisticated control than through-wall packages. Some units offer variable speed compressors and sophisticated modulating temperature control with remotely mounted sensors. Advantages and disadvantages are much as for through-wall units, but much of the maintenance is now outside the occupied area. Multi-split package systems are also an option where several room coolers are connected to one refrigeration unit. Individual control of room coolers is generally not possible with this system.

Individual reversible heat pumps are available as through-wall and split unit systems. In these the refrigeration can work in reverse, pumping heat into, as well as out of, the room (ie heating as well as cooling).

Variable refrigerant flow rate systems are relatively new. They are a special case of multi-split package heat pump systems. Several room coolers are connected directly to a single outdoor refrigeration unit. The refrigerant flow rate can be varied using a variable speed compressor in response to changes in cooling requirements. A sophisticated control system enables switching between heating and cooling modes. In more sophisticated versions indoor units may operate in heating or cooling mode independently of others. This latter arrangement offers potential energy savings when heating and cooling are required simultaneously in different zones.

These systems can be advantageous where no plant room is available and where a number of zones have different cooling and heating requirements. They offer great flexibility but, as with all distributed systems, maintenance costs may be significant.

Chillers

Refrigeration equipment is used to chill air or water in all air conditioning systems. Generally, a mechanical vapour compression system is used, although absorption refrigeration systems should be considered where waste heat is available (eg from CHP). There are a number of key issues that need to be addressed in selecting this equipment.

Firstly, can a refrigeration plant be avoided, or can its use be limited, using a free cooling technique. Various techniques are available. Secondly, if a chiller is necessary, then it must be efficient. Refrigeration efficiency is a complex topic and beyond the scope of this document, but it is important to note that the difference between the running costs of a good system and a bad one can be as much as 50%. Thirdly, is an environmentally acceptable refrigerant being used? The Montreal Protocol and EC Regulation 594/91 call for no further production of CFCs after 1996 and 1997 respectively.

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